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The National Hydrology Research Centre conducts research on issues relevant to the sound management of Canada's aquatic resources. These include the detection and prediction of climatic change, nutrients and toxics in surface and ground waters, environmental impacts on northern systems, and the integrity and health of aquatic ecosystems. In collaboration with national and international partners, NHRC scientists participate in interdisciplinary research programmes designed to address regional, national and international environmental problems.

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NATIONAL HYDROLOGY RESEARCH INSTITUTE

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Ecosystem Integrity and Cumulative Effects Assessment

Recent Activities 1994

Key Research Areas

- To identify and assess chemical, hydrological, climate and land-use related stressors on aquatic and terrestrial ecosystems
- To develop and validate bioindicators of ecosystem health and integrity
- To develop approaches to assess cumulative impacts on aquatic ecosystems
- To produce the scientific knowledge required to develop and validate guidelines for the conservation and protection of aquatic ecosystems

Ecosystem Integrity and Cumulative Effects Assessment is an innovative science program that brings together aquatic ecologists, lake and river specialists, hydrologists, biologists, and chemists to work within an integrated research framework to address some of the environmental problems affecting Canada's aquatic ecosystems. The keynote of the program is its ecosystem approach, a research perspective addressing the complex interaction among the physical, chemical and biological components of an ecosystem. This approach recognizes that environmental and economic components are fundamentally linked and a balance between them must be achieved so that human populations can manage natural resources in a sustainable manner.

Role of benthic communities in phosphorus cycling in lakes and rivers

High concentrations of phosphorus in surface waters cause serious water quality problems including toxic blue-green algal blooms and excessive benthic algal production. In the shallow lakes and rivers of the Canadian Prairies, phosphorus loading from bottom sediments represents a significant contribution to the open-water phosphorus pool, often a larger source than surface inflow. This study is designed to quantify the role played by benthic invertebrates (bottom-dwelling small animals such as aquatic insects, worms and crustacea) on phosphorus release rates from sediments to the overlying water. During the past year, experiments were undertaken to demonstrate that crayfish activity enhances nutrient release from bottom sediments, which, in turn, results in increased algal abundance. Results from this study will provide an estimate of benthic phosphorus release rates that can be used in formulating phosphorus budgets for prairie lakes and rivers.

Water quality in riverine systems

In Canada and other industrialized nations, heavy demands are placed on rivers to provide water for domestic, agricultural and industrial purposes, and to receive domestic and waste-water effluents. Such demands have jeopardized our ability to manage river ecosystems in the context of sustainable development. In particular, the increase in nutrient loading from municipal, industrial (pulp mills, for example) and agricultural sources during the past 30 years has caused deterioration in water quality and changes in the abundance and distribution of benthic communities, particularly benthic plant communities. The goal of this study is to quantify the impact of nutrient loading from municipal and industrial sources on water quality and aquatic biota, particularly on submerged aquatic plants. During the past year, a quantitative model was developed for predicting the extent of aquatic plant growth in the Nechako River under pre-regulation and post-regulation conditions. Results of these analyses were presented at the British Columbia Utilities Commission hearings on the Nechako River and figured prominently in the Kemano Completion Project Review Report prepared by the Commission.

In addition to the Nechako River study, an artificial stream system for studying aquatic macrophytes was designed and constructed beside the South Saskatchewan River, Saskatoon. Experiments were undertaken to evaluate the impact of past and future upgrades to the Saskatoon sewage treatment plant on the growth of rooted aquatic plants.

Other work includes a review of the impact of non-point sources of nutrient loading on rivers systems and development of a research plan, in collaboration with German scientists, for assessing the impact of non-point sources of nutrient loading to German rivers. This work was funded by the Green Plan International Partnerships initiative. These research projects will assist in fulfilling major DOE objectives, including development of nutrient and flow guidelines for rivers, techniques for the restoration of degraded rivers, and improvement of water quality models.

Great Slave Lake

Great Slave Lake has an extensive drainage basin, with water from the Peace and Athabasca watersheds entering the lake through the Slave River. Increased development in the Great Slave Lake watershed may affect this northern great lake, and impacts could be transferred downstream to the Arctic Ocean via the Mackenzie River. In this study, we are investigating the basic limnological features of Great Slave Lake to understand how the lake may respond to perturbations such as increased nutrient and contaminant loading and to global warming. The study's focus is contaminant pathways in the lake ecosystem, and research is in progress to determine the concentrations of persistent organic contaminants in sediments and the depositional history of such contaminants. Potential sources are long-range atmospheric transport and riverine transport.

Another study is determining organic contaminant biomagnification in Great Slave Lake food webs. Two regions are under investigation: one weakly influenced and another strongly influenced by outflow from the Slave River. Stable isotopes studies are allowing us to investigate carbon pathways and the influence of food web structure on contaminant biomagnification. Data are being compared with results of similar studies conducted in other regions of the Northwest Territories and Yukon.

Boreal park lakes

Prince Albert National Park is located in the boreal region of Saskatchewan, and is the site of several, national and international research studies. Two of the largest lakes in the Park, Crean and Waskesiu, have experienced various anthropogenic perturbations: for example, an intense commercial fishery operating during the 1920s and damming of lake inflows and outflows during the late 1930s. As part of its lake ecosystem management program, Parks Canada is considering various restoration actions to return the lakes to their early conditions and to minimize the adverse influences of human activities on their natural properties. NHRI's ongoing studies in the Park are addressing many of the areas of concern.

Two studies assessed the overwintering hatching success of lake trout eggs in Crean Lake. Hatching success was moderately high and there was little evidence that increased shoreline erosion has significantly damaged historic spawning beds. It may be timely, thus, to consider remedial actions to restore the decimated lake trout population. In Waskesiu Lake, researchers have examined seasonal nutrient, zooplankton (aquatic microscopic animals), and phytoplankton (free-floating microscopic plants) dynamics and quantified primary production. These data are providing an enhanced understanding of the limnology of boreal lakes that can then be compared with the information generated from prairie lake programs. NHRI is assisting Parks Canada in developing the framework for a long-term monitoring program for the offshore waters of Waskesiu Lake. Nearshore studies focus on detailed fish habitat characterizations (using a GIS system) and fish associations within these habitats, facilitating the assessment of the potential impact of dam removal on the littoral zone fish communities.

Bioassay development for ecotoxicological applications

Toxicity tests can be divided into two general categories. Acute toxicity tests provide data quickly but typically measure LC50s (the dose at which half the test subjects die) rather than ecologically relevant end-points such as growth and reproduction. Chronic toxicity tests provide data of greater ecological relevance, but are longer in duration. To provide an alternative to these methods, NHRI scientists are developing a rapid-response bioassay to assess the impacts of toxic exposure, specifically to whole and fractionated pulp mill effluent. The bioassay employs changes in feeding behaviour of *Daphnia magna,* water flea, because feeding inhibition is an indicator that is quickly and easily obtained, and yet is directly relevant to growth and reproduction. The impetus for this study arises from discussions with researchers in the European Union involved in the METIER (Modular Ecotoxicity Tests Incorporating Ecological Relevance) Project who are developing similar bioassay techniques for use in testing potential negative effects of specific compounds in the regulatory context. With a focus on effects of exposure to whole or fractionated pulp-mill effluent, NHRI's research addresses the requirements of a successful biomonitoring program.

Identification of effluent sources in riverine food webs by stable isotopic analyses

Improving our knowledge of tropic linkages in riverine communities is critical if we are to understand the pathways through which contaminants accumulate in the food web. Unfortunately, conventional techniques (e.g., gut-content analysis) for assessing tropic linkages are laborious and often

inaccurate. To address this problem, NHRI is conducting stable isotopic analyses on tissues from aquatic organisms such as fish, insects, and plants to reveal more accurately the trophic status of riverine biota. NHRI scientists are exploring the feasibility of using the stable isotopes of carbon, nitrogen and sulphur to determine the extent to which pulp mill and sewage treatment plant effluents are incorporated and dispersed into downstream foodwebs. Effluents can impose unique carbon, nitrogen and sulphur signals onto the food chain, and thus stable isotopic analyses of aquatic organisms may serve as markers of the spatial extent to which effluents affect riverine communities. Research projects are currently underway on the South Saskatchewan and Thompson rivers.

Effluent impacts on secondary producers in river ecosystems

This project addresses two primary requirements of an informed management strategy for riverine ecosystems: understanding what the consequences are to downstream food webs of upstream effluent loadings, and comprehending which components of the effluent are the important contributors to effects observed below pulp mill effluents. Presently, we cannot predict the effect on ecosystem health of further loadings to these ecosystems because the effluents contain both nutrients that stimulate the algal and microbial food supplies of invertebrates; and contaminant stressors that can reduce invertebrate growth and production. The role played by this nutrient and contaminant interaction in setting the production of key trophic linkages in riverine receiving waters can only be revealed through experimentally-based research designs.

Just such a research design has been implemented at NHRI. Partial flow-through mesocosms, "artificial streams," were developed to investigate the interactive effects of effluent stressors and nutrient enrichment on benthic invertebrate communities of the Fraser and Athabasca rivers. The transportable system consists of 16 mesocosms used to investigate the impacts of nutrients and contaminants from effluents (for example, combined pulp mill and sewage) on multi-level riverine food webs: that is, on biofilm and invertebrates. To date, our results indicate that pulp-mill effluent loadings act primarily on the riverine benthos (bottom-dwelling organisms) to increase primary and secondary production. The increased production appears to be caused by the phosphorus and nitrogen loading from the effluent. This project is funded by the Fraser River Action Plan, the Northern Rivers Basin Study and NHRI.

Evaluation of aquatic ecosystem health in Kootenay National Park

In a project jointly funded by Parks Canada and NHRI, Institute scientists are developing an ecosystem health evaluation program for Kootenay National Park, based on the use of riverine invertebrate communities as biological indicators. The composition and structure of benthic invertebrate communities in flowing waters are closely linked to the surrounding terrestrial landscape and instream environment gradients; moreover, benthic community composition is modified within watersheds, particularly in response to hydrologic gradients. These characteristics make riverine invertebrate communities appropriate candidates for use as ecosystem health indicators in mountain watersheds, and, because this approach attempts to identify basic ecological patterns through the linkage of terrestrial and aquatic habitats, it should be applicable to the other mountain parks in the area.

Baseline information for the evaluation program is acquired through a short, but intensive, assessment of the benthic invertebrate community of streams and rivers. The experimental design of this assessment relates benthic communities to key biotic and abiotic variables, including stream order and hydrology, soil and vegetation type. There are three main phases to the project. Existing information on the landscape, ecozones, hydrology, stream geomorphology was examined in order to establish major habitat blocks to be replicated across the Park. Next, sampling sites were located within these blocks and samples of periphyton, organic detritus, benthic invertebrates and key water quality variables (phosphorus, nitrogen etc.) collected at each site once during the late-summer 1994; finally, multivariate analysis is now in progress to identify archetypical communities throughout Kootenay National Park.

Personnel

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Water quality modelling of river systems

Culp, Joseph M. and Patricia A. Chambers, Editors. Water Quality Modelling for the Northern River Basins Study. NHRI Symposium No. 13. 90p.

A collection of papers from an international workshop to review and assess available modelling approaches for estimating the impact of biological oxygen demand (BOD) and nutrient loadings on the water quality of the Peace and Athabasca river systems.

Selected Publications

Barko, J.W., C.S. Smith and **P.A. CHAMBERS.** 1994. Perspectives on submersed macrophyte invasions and declines. Lake and Reservoir Management 10(1): 1-3.

CASH, K.J., M.H. McKee and **F.J. WRONA**. 1993. Short- and long-term consequences of grouping and group foraging in the free-living flatworm *Dugesia tigrina*. Journal of Animal Ecology 62: 529-535.

CHAMBERS, P.A. 1994. Submersed macrophytes in the Canadian Prairies: dealing with home-grown problems. Lake and Reservoir Management 10(1): 5-8.

CHAMBERS, P.A., J.W. Barko and C.S. Smith. 1993. Evaluation of invasions and declines of submersed aquatic macrophytes. Workshop Summaries. Journal of Aquatic Plant Management 31: 218-220.

CULP, J.M. and T.A. Crowl. 1994. Non-visual cues in benthic predator-prey systems: introduction to a symposium. Journal of the North American Benthological Society 13(2): 266-267.

CULP, J.M., G.J. Scrimgeour and C.E. Beers. 1994. The effect of sample duration on the quantification of stream drift. Freshwater Biology 31:165-173.

CULP, J.M. and G.J. Scrimgeour. 1993. Size-dependent diel foraging periodicity of a mayfly grazer in streams with and without fish. Oikos 68: 242-250.

EVANS, M.S. 1993. Toxic contaminants and Great Lakes ecosystem health: current understandings and strategies for improved assessments. Journal of Aquatic Ecosystem Health 2: 87-93.

EVANS, M.S. 1993. Paleolimnological studies of saline lakes. Journal of Paleolimnology 8: 97-101

EVANS, M.S. and J.V. HEADLEY. 1993. A March 1992 investigation of Great Slave Lake: organic contaminant concentrations in lake sediments and water column characteristics. NHRI Contribution Series No. CS-93020. 46 p.

EVANS, M.S., B.A. Manny and T.E. Golumbia. 1994. Lake trout eggs: in situ hatching success in Crean Lake, October 1990-May 1991 studies. NHRI Contribution Series No. CS-94012. 49 p.

Scrimgeour, G.J. and **J.M. CULP**. 1994. Foraging and evading predators: the effect of predator species on a behavioural trade-off by a lotic mayfly. Oikos 69:71-79.

Scrimgeour, G.J., **J.M. CULP** and **K.J. CASH**. 1994. Anti-predator responses of mayfly larvae to conspecific and predator stimuli. Journal of the North American Benthological Society 13(2): 299-309.

Scrimgeour, G.J., **J.M. CULP and F.J. WRONA**. 1994. Feeding while avoiding predators: evidence for a size-specific trade-off by a lotic mayfly. Journal of North American Benthological Society 13(3): 368-378.

Scrimgeour, G.J., **J.M. CULP and N.E. GLOZIER**. 1993. An improved technique for sampling lotic invertebrates. Hydrobiologia 254: 65-71.

WASSENAAR, L.I. and J.M. CULP. 1994. Identification of pulp mill effluent signatures in riverine food webs by stable isotopic analyses. In *Proceedings of the 2nd International Conference on Environmental Fate and Effects of Bleached Pulp Mill Effluents. Vancouver, B.C., 6-10 November , 1994.*

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NHRI Monographs

1995 Price List

SYMPOSIA

Proceedings of the Symposium on Interbasin Transfer of Water: Impacts and Research Needs for Canada. 1988. NHRI Symposium No. 1, 504 p. ISSN 0838-1984, ISBN 0-662-16017-7, Cat. En36-512/1E. S&H only

Proceedings of the Prairie Drought Workshop. 1988. NHRI Symposium No. 2, 366 p. ISSN 0838-1984, ISBN 0-662-56788-9, Cat. En36-512/2. **Out-of-print**

Proceedings of the Workshop on Mackenzie Delta: Environmental Interactions and Implications of Development. 1991. NHRI Symposium No. 4, 195 p. ISSN 0838-1984, ISBN 0-662-17686-3, Cat. En36-512/4E. $15.00

Proceedings of the Workshop on Applications of Remote Sensing in Hydrology. 1990. NHRI Symposium No. 5, 386 p. ISSN 0838-1984, ISBN 0-662-17687-1, Cat. En36-512/5E. S&H only

Northern Hydrology: Selected Perspectives. 1991. Proceedings of the Northern Hydrology Symposium. NHRI Symposium No. 6, 532 p. ISSN 0838-1984, ISBN 0-662-18742-3, Cat. En36-512/6E. $28.00

Proceedings of the Conference on Aquatic Ecosystems in Semi-Arid Regions: Implications for Resource Management. 1992. NHRI Symposium No. 7, 375 p. ISSN 0838-1984, ISBN 0-662-19029-7, Cat. En36-512/7E. Soft cover $15.00, Hard cover $25.00

Proceedings of the Workshop on Using Hydrometric Data to Detect and Monitor Climatic Change. 1992. NHRI Symposium No. 8, 247 p. ISSN 0838-1984, ISBN 0-660-14564-2, Cat. En36-512/8E. $23.00

Proceedings of the Workshop on Soil Moisture Modelling and Monitoring for Regional Planning. 1992. NHRI Symposium No. 9, 195 p.. ISSN 0838-1984, ISBN 0-660-14744-0, Cat. En36-512/9E. $22.00

Proceedings of the Ninth International Northern Research Basins Symposium/Workshop. 1993. NHRI Symposium No. 10. 2 volume set, 919 p. ISSN 0838-1984, ISBN 0-660-14765-3, Cat. En36-512/10E. $40.00/set

Proceedings of the Workshop on Sulphur Transformations in Soil Ecosystems. 1993. NHRI Symposium No. 11, 353 p. ISSN 0838-1984, ISBN 0-662-20790-4, Cat. En36-512/11E. **Out-of-print**

Proceedings of the Workshop on Environmental Aspects of River Ice. 7th Workshop on Hydraulics of Ice Covered Rivers. 1994. NHRI Symposium No. 12, 390 p. ISSN 0838-1984, ISBN 0-660-15352-1, Cat. En36-512/12E. $20.00

Water Quality Modelling for the Northern River Basins Study (NRBS). 1994. NHRI Symposium No. 13, 90 p. ISSN 0838-1984, ISBN 0-660-15515-X, Cat. En36-512/13E. $20.00

****Application of Remote Sensing in Hydrology.** 1995. Proceedings of the Second International Workshop, 18-20 October, 1994, Saskatoon, Saskatchewan. NHRI Symposium No. 14. ISSN 0838-1984, ISBN 0-660-15800-0, Cat En36-512/14E.

SCIENCE REPORTS

Northern Hydrology: Canadian Perspectives. 1990. NHRI Science Report No.1, 308 p. ISSN 0843-9052, ISBN 0-662-17076-8, Cat. En36-513/1E. $18.00

Working Group on River Ice Jams: Field Studies and Research Needs. 1990. NHRI Science Report No. 2, 121 p. ISSN 0843-9052, ISBN 0-662-17566-2, Cat. En36-513/2E. S&H only

Northern Hydrology: International Perspectives. 1994. NHRI Science Report No. 3, 215 p. ISSN 0843-9052, ISBN 0-662-18743-1, Cat. En36-513/3E. $18.00

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Glacier Mass Balance Measurements: Manual for Field and Office Work. 1991. NHRI Science Report No. 4, 224 p. ISSN 0843-9052, ISBN 0-662-19000-9, Cat. En36-513/4E. $15.00

Environmental Aspects of River Ice. 1993. NHRI Science Report No. 5, 155 p. ISSN 0843-9052, ISBN 0-662-20820-X, Cat. En36-513/5E. $20.00

***Mass Balance of Axel Heiberg Island Glaciers, 1960-1991: A Reassessment and Discussion.** 1995. NHRI Science Report No. 6, 168 p. ISSN 0843-9052, ISBN 0-662-15342-4, Cat. En36-513/6E. $20.00

***Snowcover Accumulation, Relocation and Management.** 1995. NHRI Science Report No. 7, 144 p. ISSN-0843-9052, ISBN 0-660-15816-7, Cat. En36-513/7E. $22.00

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Sustainable Ground Water Resources

Recent Activities 1994

Key Research Areas

- Investigation of natural processes in subsurface environments
- Determination of the movement of chemicals, nutrients, and toxic substances in ground water
- Evaluation of microbial processes and transformation of contaminants in subsurface environments

Research in NHRI's *Sustainable Ground Water Resources* Program directly supports Environment Canada's objectives of reducing pollution of water resources by pesticides and wastes, remediating contaminants in ground water, and establishing sustainable management strategies for sectors such as agriculture. As well as carrying out an extensive field program, NHRI ground-water scientists conduct research using laboratory mesoscale models at the National Hydrology Research Institute.

GROUND WATER FLOW AND CONTAMINANT TRANSPORT IN GLACIAL DEPOSITS

A large proportion of Canada's ground water occurs in glacial deposits. This project focuses on the behaviour of contaminants in such deposits and aims to develop improved measurement techniques and predictive models for the movement of contaminants in clays and tills, and in adjoining aquifers. The work involves a combination of field investigations, laboratory experiments, and modelling.

Contaminant transport in the Condie Aquifer

One component of the research deals with an 8 km-long, very narrow contaminant plume in a confined aquifer near Regina, Saskatchewan. NHRI research has shown that horizontal spreading (transverse horizontal dispersion) of this plume is much smaller than for any other case reported in the literature. The minimal transverse dispersion appears to be due to the extremely steady flow in the aquifer, suggesting that fluctuations of ground water flow direction may be the dominant mechanism of dispersion for many contaminant plumes - especially when they occur in shallow unconfined aquifers subject to large fluctuations of ground water flow directions. Aquifer heterogeneity, thus, may not be as important a factor in dispersion as it is usually assumed to be. While one can expect wide contaminant plumes in unconfined aquifers, it appears that ground water contamination can also occur as very narrow plumes, especially in confined aquifers with steady flow. Such narrow plumes may easily escape detection by standard widely-spaced deployments of monitoring wells.

Ground water contamination by potash mine brines

The ten potash mines in Saskatchewan all have large waste-salt disposal areas and brine ponds. Investigation of subsurface brine mitigation at each of the mine sites has been carried out in collaboration with the Saskatchewan Research Council. The results of this study show that brine migration through clays and tills can be analyzed and predicted on the basis of current conceptual and numerical models for flow and contaminant transport in low-permeability materials. Flow in fractures and diffusion in unfractured materials are the dominant mechanisms controlling contaminant transport. The depth of penetration of the contaminants is largely controlled by the depth of fracturing and this depth can vary from a few metres to tens of metres below ground surface. The work also led to the development of a radial-diffusion technique for determining contaminant concentrations, effective porosity, and effective diffusivity for undisturbed core samples of clays and tills.

Monitoring wells - misleading data

Monitoring wells in low-permeability materials are particularly susceptible to yielding unreliable results. Review of data obtained in the course of previous investigations showed that even minute leaks in well casings can result in misleading water quality and water level data. Leaching of

chemicals from the sealant materials used to isolate the intakes of the wells can also affect the water quality in the monitoring wells. This effect is being evaluated for the case of sand-bentonite sealing materials. Increasingly, it is becoming apparent that the use of monitoring wells to determine water quality with low-permeability formations is a questionable technique. Such wells need to be designed and constructed with more than usual care, and in many cases it may be better to use alternative methods.

Contaminant transport in confining layers

Thick non-fractured clays protect aquifers throughout the world. Although the confining nature of clay tills and shales is difficult to characterize, compelling economic and public health issues demand a thorough understanding of the transport of solutes through such deposits. To gain this knowledge, NHRI scientists are studying the evolution of ground water chemistry in aquifer systems, and assessing solute transport (including contaminants) mechanisms in slowly permeable deposits. These questions are important to industries conducting deep-well injection and to agencies interested in protecting existing ground water resources and controlling the development and maintenance of wetlands and salinized areas in the prairie environment. The research is a collaborative effort between NHRI and several organizations: two research institutes in Germany via the Canada/Germany agreement, Argonne National Laboratory , U.S.A., the University of Illinois, the Alberta Government, the Prairie Farm Rehabilitation Administration, the Saskatchewan Research Council, and the University of Saskatchewan.

Nitrate Contamination - Abbotsford Aquifer, British Columbia

Extensive nitrate contamination of ground water in the Abbotsford aquifer to levels above drinking water guidelines is a major problem in the Fraser Lowlands of southwestern British Columbia. Of 117 wells sampled, 54% had nitrate concentrations exceeding the drinking water limit. Approximately 80% of the study area had ground water nitrate concentrations exceeding 40 mg/L NO_3^-. Potential nitrate source materials were poultry manure N and ammonium based fertilizers. The $\delta^{15}N$ of solid poultry manure samples ranged between +7.9 and +8.6 $^{o}/_{oo}$. Four brands of commonly used synthetic fertilizers had $\delta^{15}N$ values between -1.5 and -0.6 $^{o}/_{oo}$. Ammonia volatilization caused the $\delta^{15}N$ of ground water nitrate produced from poultry manure N to range between +8 and +16 $^{o}/_{oo}$. The $\delta^{18}O$ values of ground water nitrate, by contrast, mostly ranged between +2 and +5 $^{o}/_{oo}$. This narrow range of $\delta^{18}O$ values fell within the expected range of nitrate produced by nitrification of reduced nitrogen forms such as poultry manure N and ammonium fertilizers, and had a similar range of $\delta^{18}O$ values as nitrate in the upper part of the unsaturated zone below raspberry fields and beneath former manure piles. The $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ data indicated nitrate in the aquifer was predominantly derived from poultry manure and to a lesser extent from ammonium based fertilizers. The $\delta^{18}O\text{-}NO_3^-$ data suggested the nitrification process occurred mainly in the summer months, with the soil nitrate produced subsequently flushed into the aquifer during fall recharge. The $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ data further indicated that no significant bacterial denitrification is taking place in the Abbotsford aquifer, and, therefore, it would take many years for the aquifer to restore itself. The findings of this important study were detailed in a report to the British Columbia Ministry of the Environment and to the Fraser River Action Plan. They were presented also at the Western Canada Symposium on "Agricultural Impacts on Water Quality."

Humic substances in ground water

High concentrations of dissolved organic carbon (5 mg C/L) are found in some ground water systems. High DOC, specially in the form of humic polymers, in drinking and treated water supplies is linked to chloroform and methane production, poor water quality, fouling, and high iron concentrations. Other research has shown DOC is associated with heavy metal (actinide) transport. Only a few studies concerning the origin and transport of DOC in ground water systems exist, and the subject is not well understood; however, contributory factors to high DOC concentrations could be sediment-water interaction, pH gradients, ion exchange, or flux from soils. Isotopic and geochemical characterization of DOC and humic substances in ground water provides a powerful tool to distinguish between recent and fossil sources, and aids in understanding the potential mechanisms and processes responsible for humification of ground water. In Canada, research has focused on organic matter sources and transport through low permeability deposits. In Denmark, a 5 year project on the characterization of DOC in humic ground water is near completion. The collaboration with Danish researchers on sampling, analyses, and organic and isotopic characterization of DOC is expected to lead to a better understanding of the mechanism and importance of DOC in natural and contaminated ground water systems. The research will aid in establishing further guidelines for acceptable levels of polymeric organic acids in ground water.

Distribution of hydrocarbon contaminants in subsurface soils

Hydrocarbon contamination of soils and ground water is a growing problem. Often, the cause is the buried tanks and pipelines associated with the distribution and storage of gasoline and diesel fuels. In some areas of Canada, however, the contamination of the subsurface by natural gas condensates is widespread. The safe and cost-effective

remediation of sites contaminated by hydrocarbons requires knowledge of the fundamental processes responsible for their infiltration and redistribution in partially saturated, fine grain soils - particularly in parts of western Canada where soils are heavily desiccated and fractured due to the semi-arid climate in many regions. The long-term goals of this study are to refine sampling and analytical protocols to determine the processes controlling the distribution of hydrocarbon products in unsaturated fine grained soils; and to determine the factors controlling the partitioning of hydrocarbon contaminants in unsaturated soils. To date, sampling and analytical methods for delineating benzene-contaminated soils and ground water have been implemented and a patent submitted for a soil-probe for sampling hydrocarbons.

Information gained from this work will support initiatives to cleanup contaminated sites, protect the quality of drinking water, and provide management tools for environmental assessment of hydrocarbon spills.

Ground water biotechnology

Biotechnological approaches to both the containment of contaminants and the in situ remediation of contaminated sites are attracting increased interest. The introduction of microorganisms into the subsurface, however, raises regulatory concerns (CEPA) about predicting the fate of introduced organisms (either engineered or selected from the environment). Understanding and predicting the fate of microorganisms in the subsurface is also a major impediment to the field application of biotechnology. NHRI, in collaboration with the USEPA, University of West Florida, GSF (Munich) and the University of Waterloo, has undertaken research to address these questions and concerns about the application of biotechnology in ground water environments. Transport experiments using a TCE degrading bacterium are being carried out at three scales using model silica sand and aquifer materials. Factors such as the influence of the presence of other microorganisms on transport are also under investigation. The results of these and other experimental approaches contribute to development of a numerical model for predicting the transport and fate of bacteria in the subsurface. The models and understanding of fate of organisms in the subsurface developed may provide a management tool for CEPA implementation.

Subsurface process studies

The use of mesocosms has gained ground in process studies, including those validating pesticide fate and impacts. Mesocosms are large enough to contain all the components of interest, while permitting "natural" behaviour. They are expensive to construct, to operate, and to acquire data from; however, the returns on investment can be significant. The principal question surrounding studies conducted in mesocosms concerns the transferability of results to natural ecosystems. The mesocosm can provide an important link in the validation and extrapolation of results to ecosystems or significant subunits. For example, NHRI studies published in 1993 demonstrated the utility of mesocosms for investigations of microbially derived CO_2 in the unsaturated zone. In those studies, the mesocosm approach allowed estimation of the steady state concentrations of CO_2 and time to steady state. Results suggested that microbial CO_2 production responds quickly to hydraulic perturbations. Mass balance calculations possible in a mesocosm showed that most CO_2 diffused to the atmosphere and fluxes in recharge waters were minimal. A comparison of estimates of total flux based on measurements versus microcosms mesocosm showed the latter to overestimate CO_2 production by an order of magnitude. The results of this mesocosm study also supported the contention that microbial activity below the soil horizons may contribute substantially more CO_2 to the atmosphere than indicated by previous studies. Long term experimentation in mesocosms, thus, can provide valuable insight into biogeochemical processes in natural subsurface systems.

In our ongoing studies in this area we have also developed a well instrumented field site within a prairie ecosystem to provide a defined link between a mesocosm and the ecosystem from which it was removed.

Acid mine drainage

Acid mine drainage (AMD) is the most significant environmental problem facing the mining industry today. It can lead to serious detrimental effects on both surface- and ground-water resources. NHRI is engaged in collaborative research to gain a better understanding of acid generation and metal leaching processes. A MEND (Mine Environment Neutral Drainage Program) project on prediction and prevention of acid rock drainage from a geological and mineralogical perspective has been completed and an industry-funded project on mineralogical controls of sulphide oxidation begun. The latter addresses the interplay of geochemical, electrochemical and microbial mediation processes in the oxidation of natural sulphide assemblages. Research results are expected to enable accurate prediction of the onset of AMD and to aid in the development of preventive measures that will ensure environmental health and sustainable mining practices.

AVI mapping

In 1993, NHRI initiated a project to prepare ground water vulnerability maps for four areas on the Manitoba-Saskatchewan boundary and six on the Saskatchewan-Alberta boundary for the Prairie Provinces

Water Board. The maps were prepared on a 1:250,000 horizontal scale with each map covering one degree of latitude. The mapping used the aquifer vulnerability index which is based on two parameters, the thickness and the permeability of materials overlying the nearest-to-surface aquifer. The index was developed from a pilot study completed by NHRI in 1991/92 to determine the feasibility of mapping ground water vulnerability to surface sources of contamination. The data used to compute the aquifer vulnerability index are readily available from provincial water well drillers' reports. The map series is now complete and can be obtained from the Prairie Provinces Water Board.

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NATIONAL HYDROLOGY RESEARCH INSTITUTE

INSTITUT NATIONAL DE RECHERCHE EN HYDROLOGIE

Cold Regions Hydrology and Ecology

Recent Activities 1994

Key Research Areas

- Investigation of hydrological processes in northern environments
- Forecasting environmental effects of flow regulation/diversion on northern aquatic ecosystems
- Determination of the impact of forestry practices on boreal ecosystems

Scientists in the *Cold Regions Hydrology and Ecology* Program focus their research on the hydro-ecology of Canada's North. Both the quality and quantity of northern aquatic resources can be compromised by resource development, pollution, water diversion, and climate variability. Studies in this program are designed to gain a better understanding of the impacts of these threats on northern aquatic ecosystems and to increase scientific knowledge of the hydrological, biophysical, chemical and ecological processes unique to the North.

Model forest hydrology: sustainable forestry

This research project conducted near Waskesiu in Prince Albert National Park, Saskatchewan, was initiated to develop new techniques to support sustainable forestry management. The integrity and sustainability of the southern boreal forest of western Canada are directly related to fluxes of energy, water and nutrients. Sensitive to surface water and climate conditions, the boreal forest acts as a water and climate regulation system, interacting with the atmosphere and soils to produce the specific conditions of water flow, availability, nutrient status and surface climate to which it has adapted. However, harvested forest blocks and regenerating forest stands regulate water and climate very differently than do undisturbed boreal forest stands, due to differences in vegetation and soils and their effects on the partitioning of incoming atmospheric energy and water flow.

NHRI scientists are attempting to determine the precise nature of the differences in self-regulation capacities between undisturbed and harvested forests. Currently, the team is conducting field experiments on winter nitrogen cycling, snow processes, evaporation processes and soil water infiltration - experiments duplicated in various forested and clearcut sites. A long-term goal of the research is to develop process-based models of forest hydrology to assist in assessing the impacts of climatic change and of harvesting on boreal forest ecosystems.

Aqueous contaminant transport

The fragile ecosystems in Canada's North are very sensitive to pollution; however, the mechanisms and processes of contaminant transport in the sub-surface are not well understood and the role of ground water in the hydrological cycle in permafrost areas has rarely been studied. In collaboration with the Water Resources Division of the Northern Affairs Program, Whitehorse, this study is designed to gain a better understanding of aqueous contaminant transport and ground water hydrology in the northern environment - knowledge essential for an effective strategy to safeguard the integrity and productivity of the Arctic. Through stable isotope analyses and mass balance calculations of dissolved constituents, the influence of ground water on the surface water hydrograph will be investigated and the role of bacteria in metal attenuation in northern drainage systems thoroughly examined. Preliminary sampling has been carried out at a number of northern field sites including Engineer Creek along the Dempster Highway and Wolf Creek near Whitehorse, Yukon.

Ecological effects of ice jams: Peace Athabasca Delta

Natural ice jams play an important role in recharging the perched basins and other wetland areas of numerous northern deltas. In the Peace Athabasca Delta, however, changes in the frequency, timing, and character of ice jamming and flooding have led to disturbances in the seasonal pattern of water distribution, with impacts on the

health and integrity of the delta ecosystem. What is not yet clear is the cause of these changes. Is flow regulation of the Peace River the culprit? Or, are natural variations in meteorological and ice conditions contributing factors? Working within the Peace Athabasca Delta Technical Studies Program of Parks Canada and the research framework of the Northern River Basins Study, an NHRI research team has launched a project to provide answers to these questions -scientific information to support a long-term sustainable management strategy for this large ecosystem. Current work includes studies of what types of weather, water levels and ice conditions lead to spring ice-jam flooding in the Peace-Athabasca Delta: determining how flow regulation has altered the shape and size of the Peace River water channel and how vegetation along the river banks has been affected: assessing the effects of flow regulation by the Bennett Dam on the water levels of the Delta: and modelling Peace River flows for open water and ice covered conditions from the Bennett Dam in British Columbia to Peace Point in Wood Buffalo National Park. Ultimately, the data from these studies will provide the basis of an interpretive report that will distinguish the effects of flow regulation from those of natural hydrometeorological variations on the ice-flood regime.

Artificial Ice dams

An innovative project to improve the water-balance situation in the Peace Athabasca Delta is now in progress. NHRI is advising Parks Canada Delta Project Officers on construction of artificial ice dams that will temporarily block waters and cause flooding to selected regions of the Delta. Borrowing technology from the off-shore oil industry and the ice road construction industry, a preliminary test program is under way to create non-permanent ice structures using spray ice. The ice is produced simply by spraying water into the atmosphere using a nozzle and a high pressure pump. As the water jet travels upwards in an arc to apogee, it breaks up into droplets varying in size from 1-10 mm, thereby increasing the heat transfer between the water and the cold air. The rapidly cooling droplets eventually cool to a point where an initial shell of ice is produced and continues to thicken with time. During the test program, depositional control proved to be excellent, allowing for the structure to be shaped according to requirements. Should this approach prove successful, researchers are hopeful they can remediate the problems presently evident in the vegetation regime and ecosystem integrity of the Delta.

Under-ice circulation experiment

To gain a better understanding of the importance of under-ice circulation to the transport of oxygen and nutrients in lake ecosystems, NHRI has begun a new study at Waskesiu Lake in northern Saskatchewan. Ice covered lakes are insulated from the usual turbulence sources such as near-surface shear and breaking gravity waves. The penetration of solar radiation through ice and snow at the surface can produce gravity currents between a confined bay and the main body of the lake when the mean depth differs significantly between the two. At the mouth of the bay, the gravity current takes the form of a two-layer flow with inflow to the bay occurring near the surface and outflow near the bottom. This flow is an important distribution mechanism for oxygen and other chemical and biological constituents in lakes, and an important factor in sustaining biological resources in ice-covered lakes. The water exchange through the narrows makes an important contribution to the residence time of both the lake and the bay. Similar circulations occur between the littoral zone and the deep part of the lake, and these baroclinic flows are extremely important to lake ecology since they constitute the only directed circulations that occur in the lake in winter.
A preliminary experiment conducted in March 1994 determined that the under-ice circulation between Waskesiu Lake and Waskesiu Bay is driven by solar energy that penetrates the ice in spring. Work continues to determine the magnitude of the circulation of water through the Narrows between Waskesiu Lake and Waskesiu Bay throughout the winter and to assess the importance of the under-ice circulation for the transport of oxygen and nutrients between the bay and the lake.

Runoff processes in high latitude permafrost basins

The growing concern for the environmental integrity of Canada's North has spurred a need to improve our understanding of the flux of snow through cold regions. Snow plays a dominant role in the flux of water and energy in much of Canada. In many areas it comprises over 50% of annual precipitation, and its rapid melt in the spring often results in the largest runoff event of the year, with important implications to the integrity of ecosystems, water supply, and flood forecasting. Snow is also a significant factor in the cycling of nutrients and toxic substances. Unfortunately, there is little information on the magnitude of water or energy in cold regions ecosystems, or the processes controlling them. This deficiency is partially due to our lack of understanding of snow processes in general, and of the unique aspects of cold snow/soil phenomena in particular. This study will increase our understanding of these phenomena and will help in forecasting the environmental effects of flow regulation/diversion, water availability, and the role that vegetation (forest vs. tundra) plays in controlling runoff in permafrost regions of northern Canada.

Mackenzie Delta hydrology and ecosystem interactions

Important ecological characteristics of the approximately 25,000 lakes in the Mackenzie Delta are determined by a combination of hydrologic and biogeochemical interactive processes. Cold-regions scientists at NHRI are conducting a series of experiments in the Delta to gain a more comprehensive understanding of these processes that will enable them to develop physically-based models for better forecasting of environmental effects of flow regulation/diversion on the aquatic ecosystems of the Mackenzie Delta. The long-term goals of this study are to determine the impact of changes in hydrologic regime of the delta channels on the hydrology and chemistry of lakes in the Mackenzie Delta. Current work includes an analysis of the physical/biological impacts of ice jam flooding on delta lakes.

Frazil ice

The formation of frazil ice (slushy accumulation of ice crystals) in northern rivers can have significant impacts: for example, on the availability of water for hydropower development. An NHRI study of the processes involved in frazil ice formation is now nearing completion, with a final report due in July 1995. The study has been conducted in collaboration with B.C. Hydro, Manitoba Hydro, Hydro Québec, the New York Power Authority, and the National Water Research Institute in Burlington, Ontario, and its results can be used in the assessment of the ecological effects of developing northern hydro-power resources.

Snow chemistry

Snowmelt provides the most important annual hydrochemical flux to soils, streams and lakes in northern Canada. Some important components of this hydrochemical flux are nitrogen, the availability of which limits the primary productivity of boreal forests, and various anthropogenic pollutants, such as sulphates, associated with the arctic aerosol haze. The processes of over-winter and melt metamorphism (structural changes), biological consumption within the wet snowpack, and frozen soil infiltration vs. runoff are not well understood; hence, few studies have demonstrated either the role of snow cover in delivering nitrogen and inorganic contaminants to northern ecosystems or their impact on northern ecosystems. This research project is unique in that it will not only explain the introduction of nitrogen and contaminants to northern ecosystems but will actively link to research that demonstrates the impact to ecosystem integrity. To meet these objectives, studies are in progress to determine the impact of blowing snow and accumulation processes, the time and concentration of release from the snowpack, and the role of photo-chemical processes. Given the importance of the release of nitrogen to boreal forest ecosystems, research results will be of value to sustainable forest management initiatives.

Snow surface processes in hydrological and global circulation models

Global warming in high latitudes may produce a pronounced feed-back effect as the winter/spring albedo declines; moreover, water supplies at the surface and in the atmosphere will be strongly affected by anticipated higher evaporation fluxes. The parameterization of snow in hydrological models and Global Circulation Models (GCMs) is presently quite crude, a serious shortcoming in Canada where much of the land is snowcovered for over 50% of the year. Hydrological models and GCMs presently ignore surface snow processes such as sublimation of blowing snow, which returns as much as 75% of the seasonal snowfall to the atmosphere before melt commences; and sublimation of intercepted snow, which returns 30-40% of seasonal snowfall. These processes are extremely sensitive to land cover and hence quite variable, even over small-scales. The overall goal of this project is to improve and verify the representation of surface snow redistribution, energy exchange, phase change and water vapour fluxes within lumped and distributed hydrological models and within Global Circulation Models. The work will contribute substantially to the development of physically-based, hydrological models for Canada as well as provide critical improvements to GCM performance in climate change prediction exercises.

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Detection and Assessment of Climate Change

Recent Activities 1994

Key Research Areas

- Detect and assess effects of climate variability and change on water resources and ecosystems
- Develop accurate hydrological models to simulate the effects of alternate climates on water resources
- Develop techniques to use glaciers as tools to assess climate change effects on water availability

Scientists in NHRI's *Detection and Assessment of Climatic Change* Program study all facets of the hydrological cycle as part of their work to develop models that can accurately predict variations in global and regional water resources in response to climate change. A particular emphasis of the Program is development of models applicable to cold regions, such as Canada's North, where the effects of global warming on aquatic ecosystems could be more pronounced. Many of the research studies support the Canadian GEWEX Program, a component of the International Global Energy and Water Cycle Experiment.

Hydrological models for the north

Accurate hydrological models are vital to the development of strategies for managing the impacts of climatic change on water resources. Existing models are not readily applicable to high latitudes, however, as they do not adequately take into account such cold-regions hydrologic processes as snowcover and snowmelt, permafrost interactions, and evapotranspiration. The need for cold-regions-specific hydrological models to detect and predict the effects of climatic variations on northern water resources has given impetus to an NHRI interdisciplinary project in which process researchers are working with modellers to construct a process-based model for northern regions.

Using hydrometeorological measurements from a research site at Wolf Creek, Yukon, scientists are working on an evapotranspiration model for permafrost mountain areas, and a snow accumulation and sublimation model for Arctic mountains. These studies deal with cold-regions hydrologic processes on the small scale. Another aspect of NHRI's research is the integration of this work with the SLURP model developed by NHRI for large-scale applications: for example, in the Mackenzie Basin. NHRI scientists are collaborating with Indian and Northern Affairs, Yellowknife, in this research, and have support from the Arctic Environmental Strategy.

Vegetation index

As part of the work to develop an alternate evapotranspiration component of the SLURP model, NHRI is developing a method of computing evapotranspiration by using algorithms based on leaf-area index. Currently, field measurements of leaf area at Wolf Creek are being compared with satellite-derived vegetation indices to develop an algorithm. If this approach is successful, the result will be a versatile method for estimating evapotranspiration using only remotely-sensed data, a valuable tool in the ongoing scientific effort to model large geographic regions for which there are very limited ground data.

Detecting climate change at the arctic treeline

The arctic treeline is a transitional zone separating the lowland boreal forest from the arctic tundra. It extends for approximately 5000 km across northern Canada, is often 100 to 200 km in width, and covers some 500,000 to 1,000,000 km2 in area. Its location is controlled by a complex interaction of phenomena, including temperature, precipitation, permafrost, location of the Arctic front, and snow cover conditions. It plays a dominant role in controlling the ecosystem, as evidenced by the very different plants, animals and traditional peoples that live on either side of this boundary. During the past, the arctic treeline has moved considerable distances in response to changing climate.

Recent work has shown that these changes in treeline have resulted in significant changes in the local environment, including increase in community productivity, increase in watershed runoff, and decreases in evapotranspiration. It is logical, therefore, to monitor environmental conditions at the

arctic treeline in order to detect the impact of climate change/variability in the coming decades. A new NHRI study located near Inuvik will examine changes in snow accumulation, runoff, soil moisture, active layer temperature and thickness, vegetation growth, and stream chemistry at a site at the arctic treeline and develop the long-term data base required to detect the impact of climate change/variability in this fragile northern ecosystem.

Radar satellite snowmelt detection

The goal of this study is to develop procedures for high-resolution satellite monitoring of mountain basin snowmelt and to integrate satellite radar measurements of snowmelt with runoff forecast techniques. This work will improve the ability to monitor the timing of peak flows and will assist in detecting the effects of long-term climate change on aquatic ecosystems.

Microwave satellite snowpack modelling

This companion study is designed to improve the accuracy of snowpack and snowmelt monitoring in northern regions. The objectives are to develop procedures for continuous monitoring of snow cover, snowpack water equivalent and snowmelt events using microwave radiometry, and to produce satellite runoff forecasts using snowpack and antecedent moisture derived from archived microwave observations of Canadian watersheds.

Glacier runoff component for distributed runoff models

The study aims to prepare a glacier component for NHRI hydrological models that can simulate watershed responses to variable climatic conditions. Glaciers are an extremely important hydrological component in many northern and mountainous basins because of their large storage capacities and their ability to influence streamflow regimes. There are a variety of simplifications that can be made to formulate a reliable glacier component for a basin-wide hydrological model. They require a better understanding of the glacier system itself and of ways to integrate the most important glacier-related processes into a physically-based conceptual model of a particular glacierized basin. Work is in progress to develop a simple model of a glacierized basin that accurately represents the glacier system and optimizes the information available from remote sensing and mass-balance measurements. The data base to support this comes from Place Glacier where glacier mass-balance measurements have been carried out for a number of years. The second part of the study will be the modification of a distributed model (SLURP) for incorporation of a glacier component. This research is conducted in collaboration with B.C. Hydro.

Glacier health and mass balance

In support of NHRI's program to characterize the long-term effects of climate change on the timing and quantity of runoff from glacierized basins, work continues to improve techniques for *in-situ* and remote measurement of glacier mass-balance. Research is in progress at one continental-Rockies site (Peyto Glacier-Canadian Rockies), at several sites situated in the southern Coastal Ranges of British Columbia (Sentinel and Place Glaciers), and jointly with Trent University at two sites in the Eastern Arctic (White and Baby Glaciers-Axel Heiberg Island). Data are used in studies to detect secular climate variations over a variety of climatological regimes as well as to assess the inter-annual health of critical benchmark glacierized basins. In collaboration with Wilfred Laurier University, Waterloo, Ontario, work is in progress to characterize secular changes in the role played by glaciers in the runoff regime of a glacierized catchment, while a related study is examining variations in the summer low-flow regime and effects on downstream water temperature and fisheries habitat.

Glacier mass balance/fluctuation data are contributed at regular intervals to the World Glacier Monitoring Service in association with the International Hydrological Programme and the Global Environment Monitoring System.

Measurement of evapotranspiration using ground water pressure changes.

The purpose of this study is to develop a new technique for measuring precipitation and actual evapotranspiration, based on the measurement of changes of ground water pressure. Such measurements can provide important data for the study and modelling of hydrologic processes, and can contribute to the prediction of the effects of climate change on water resources. The technique may also find practical application in water balance problems such as forest water balance, irrigation efficiency, soil moisture monitoring, and real-time hydrologic modelling. Data acquired during 1993 from two test installations near Saskatoon show close correlation to recording rain-gauge records and to evapotranspiration calculated on the basis of meteorological data and measured by means of eddy-flux recordings.

Heat, energy and transport of momentum experiment (HEATMEX)

Evaporation and precipitation constitute a significant part of the hydrological cycle that could be altered by long-term changes in climate. These processes are important nationwide but are particularly important in drier parts of the country. This study will compare various methods for estimating evaporation and sensible heat transfer in the natural environment and will demonstrate the variation of

the water vapour, heat and mass exchange coefficients as a function of wind speed and atmospheric stability. The work contributes to NHRI's research to assess the impacts of climate change in semi-arid regions such as the Canadian Prairies.

GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (GEWEX)

Several NHRI scientists are participants in Canadian GEWEX, a central goal of which is to model the water and energy balance of the Canadian Arctic Basin. Research projects emphasize the unique characteristics of the water cycle in northern Canada, focusing primarily on snow and ice.

Glacial runoff and the Athabasca River: potential impact of climate warming

To gain a better understanding of the role glaciers play in the hydrologic cycle of the Athabasca Glacier Basin, NHRI scientists are collecting a variety of data including measurements of local glacier-source spring runoff, winter accumulation along a centre profile, daily surface melt at one location near the borehole casing from 1960, and glacier surface properties throughout the melt season. Their objective is to determine how well existing models can reproduce measured water balances for the region and use these findings to develop an improved model that will serve as a tool to predict and assess the impacts of global change on basin runoff from glacier-covered regions, Eventually, this physically based-runoff model modified for the Athabasca headwaters will be used with present glacier and snow extent data and past glacier fluctuation information to evaluate the impacts of various climate change scenarios on the region.

Parameterization of evapotranspiration using remotely-sensed data

In assessing the impacts of a changing climate, the correct evaluation of the role evapotranspiration will play in a modified hydrologic cycle is crucial. This is particularly true for semi-arid regions such as the Canadian Prairies and for northern regions, generally expected to experience the greatest effects of any climatic disturbances. Most current operational evapotranspiration models ignore the effects of changes in soil heat storage making them unreliable for northern regions where the effects of changes in soil heat storage on regional energy balance are considerable. NHRI is currently working on a new evaporation model for northern regions that will use remotely-sensed data in conjunction with operational algorithms and will take the particular characteristics of northern soil heat storage into account. Work is in progress at Wolf Creek Basin near Whitehorse, Yukon, a basin that contains landscapes representative of a variety of northern regions. Two sites in the watershed (a high alpine tundra site and a low-bush tundra or open forest site) have been equipped to collect the surface temperature and atmospheric humidity and temperature data required to assess the feedback algorithm, as well as the energy balance parameters required to assess the soil heat storage effects on the partitioning of incoming energy.

Biome-scale representation of snowcover development in boreal and tundra ecosystems

In this research project, scientists are studying snow processes such as interception and redistribution, sublimation and metamorphism (structural changes) to develop mathematical relationships (algorithms) that depict snowcover development in boreal and tundra regions, and to apply these algorithms in basin, global and continental-scale hydrological models. Studies are conducted at three sites: one located near Waskesiu, Saskatchewan, in the southern boreal forest, one near Whitehorse, Yukon, in the mountain forest/tundra transition, and the other near Inuvik, NWT in the boreal/arctic fringe. The southern site is representative of a non-permafrost, dry and relatively warm boreal location with a transition from coniferous to deciduous forest environment. The mountain site is representative of the sharp elevation transition from mixed boreal forest to arctic "desert" found in northern mountains. The northern site is representative of a continuous permafrost, dry and relatively cold boreal location with a transition from a coniferous forest to an open tundra environment. This project, with its emphasis on snow processes, addresses a research gap in the area of hydrological modelling: namely, the widespread tendency to overlook the transformation of water to snow when developing general circulation models .

Large-scale simulation of permafrost basins

An important aspect of NHRI's research in the detection of climate change is the development of hydrologic models suitable for use at the basin scale. In support of this goal, several modelling projects were implemented over this past year and preliminary analysis and data collection completed for two key hydrometric sites in the Mackenzie Basin. Standard hydrometric techniques are often not tractable in these regions but the use of remote sensing data offers a viable alternative for obtaining data required for hydrologic simulation. Terrain types that are hydrologically significant and unique to wetland dominated and tundra regimes were discriminated using principle component analysis. Preliminary results indicate that these terrain classifications could be used as input to Grouped Response Unit (GRU) based hydrologic models that depend on reliable estimates of hydrologically significant terrain types. Data collection and collating is complete and preliminary model runs are now in progress.

Snowcover melt in boreal and tundra ecosystems

Boreal and tundra ecosystems are characterized by long cold winters, a rapid and abrupt onset of spring, and short cool summers. As a result, precipitation accumulates on the ground as snow for 6 to 9 months of the year; the bulk of annual runoff occurs over a brief 2 to 4 week period in the spring; surface energy fluxes are greatly affected by the underlying permafrost and changing snow covered area; and the low permeability permafrost keeps most water near the ground surface. The relative importance of processes controlling water fluxes is often different from that found in more temperate climates, and, as a result, the hydrologic regime is very different and predictive models developed for other environments often do not work very well.

The objectives of this research program are to develop a better understanding of the processes controlling the energy and water fluxes in boreal and tundra ecosystems during the spring and summer periods, to develop improved predictive algorithms, and to incorporate them into hydrological models for use at a variety of scales. Field work is conducted at two existing NHRI research basins in the vicinity of Inuvik, N.W.T. The study concentrates on snowmelt runoff during the spring, but since snowpacks may play an important role throughout the summer in many tundra environments, and since soil moisture at the end of summer is extremely important in controlling frozen soil infiltration the following spring, this study will also include certain summer processes as well.

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INSTITUT NATIONAL DE RECHERCHE EN HYDROLOGIE

Sustainable Ecosystems in Semi-arid Regions

Recent Activities 1994

Key Research Areas

- Produce knowledge base for the conservation and management of prairie lakes and wetlands
- Evaluation of the effects of agricultural practices on ground water and surface water quality and quantity
- Irrigation sustainability

Research in the *Sustainable Ecosystems in Semi-Arid Regions* Program centres on threats to the biodiversity and sustainability of prairie ecosystems: for example, the impacts of contaminants on lakes and wetlands, the environmental consequences of agricultural practices on the quality and quantity of surface and ground water, and the effects of climate variability on water resources. This research supports Environment Canada's initiatives in sustainable agriculture, wetland conservation and biodiversity preservation.

WETLAND ECOSYSTEM VULNERABILITY STUDY

The Wetland Ecosystem Vulnerability Study (WEVS) is an interdisciplinary research initiative to study the impacts of environmental threats to prairie wetlands. The main study site is the St. Denis National Wildlife Area, 40 km east of Saskatoon, Saskatchewan, in the heart of the Canadian Prairies. Research focuses on the effects of agricultural practices, land uses, climate change and other factors on wetland nutrient cycling, biological productivity, food chain dynamics, and hydrological processes. Following are descriptions of individual studies conducted under this initiative.

Fate and effects of herbicides on aquatic ecosystems

The widespread use of herbicides is threatening the ecological integrity of wetlands and other aquatic ecosystems. Detection of their fate and behaviour is crucial if research is to be directed at the pertinent questions and cost-effective management strategies put into place. To improve detection methods, which are currently very costly and subject to numerous technical errors, NHRI scientists are experimenting with techniques for extracting lipids (the stored fat that provides fuel for motion, reproduction etc.) from aquatic invertebrates to analyze for contaminant levels.

Work thus far has shown that exposure of two amphipod species (freshwater shrimp) to a widely used herbicide (triallate) results in the deposition of the herbicide in the lipid-rich tissues of the amphipods. These invertebrates are crucial diet components of ducks and game fish. Experiments revealed that triallate concentrates 80 times in the tissues of amphipods and affects the reproductive performance (clutch and egg size) of the common water flea, Daphnia pulex. This research will help make clear the links among herbicide application rates, bioaccumulation in invertebrate lipid energy reserves, and transfer of herbicides to waterfowl and fish.

Phytoplankton Lipids

Algae form the base of the food chain and are, thus, an essential nutritional component in aquatic food webs. As yet, however, there is little information on the specific effects of herbicides on algae. Field data from NHRI's wetland studies have shown that single-celled algae in the genus Crytomonas are a crucial element in the direct transfer of energy to zooplankton (microscopic animals) and ultimately to vertebrates such as ducks and fish that depend on wetland productivity. Research is in progress to provide detailed information on the synergistic effects of herbicides and nutrients on the physiological condition of Crytomonas.

South Saskatchewan River

Traditional methods for assessing stress in riverine biota caused by exposure to point-source contaminants have had some success. However, these methods have several major drawbacks including high labour costs, relatively specialized taxonomic knowledge, difficulty with cause-and-effect interpretations, and a general inability to relate site-specific taxonomic data to other systems. This study of the South Saskatchewan River compares these traditional methods with

a new physiological approach based on measurements of the lipid energy reserves of periphyton (algae) and riverine invertebrates. Preliminary results suggest that the physiological approach can be used to detect and quantify the effects of point-source contaminants, such as effluent from the city of Saskatoon, on riverine biota.

Microbial biogeochemical cycles in prairie wetlands

Prairie topography is such that economically important lakes and wetlands are interspersed among cultivated fields where both fertilizers and herbicides are regularly used. Predicting the impacts and interaction of organic contaminants on these ecosystems (i.e. the cycling of contaminants through the microbial loop and their transfer through the food chain to wetland wildlife) requires a sound understanding of the biogeochemical cycles, the dominant organisms involved, and the controlling factors. Experiments were conducted at Redberry Lake in central Saskatchewan to test the effects of herbicide, nutrients and dissolved organic carbon (DOC), singly and in combination on the bacteria and phytoplankton (free-floating microscopic plants) of the lake. Results indicate that the herbicide (triallate) reduces the amount of phytoplankton growth, but additions of nutrients (nitrogen plus phosphorus) overcome this. Herbicide added on its own has a negative effect on bacterial numbers, production and metabolism. When nutrients are added, however, the bacteria appear to use the herbicide as a carbon source. Further experiments suggest that the large pool of naturally-occurring, dissolved organic carbon in this lake is unavailable for microbial uptake, as is the relatively high concentration of phosphorus. Moreover, measures of bacterial production, metabolism and numbers were higher in microcosms enriched with nitrogen, phosphorus and a labile DOC source than in those enriched with nitrogen and phosphorus or DOC alone. These results suggest that organic contaminants entering Redberry Lake will be degraded slowly unless accompanied by an addition of nitrogen and phosphorus. If there is little or no microbial degradation of organic contaminants, these substances may accumulate in the system. The data also point to the need for a re-calibration of the empirical models commonly used by water managers to assess the impacts of changing nutrient loads on the quality of surface waters in the prairie ecozone. Clearly, these models are not accurate for the thousands of prairie saline water bodies.

Plankton studies in prairie lake ecosystems

Prairie lakes typically are shallow, productive systems characterized by short growing seasons. Many are saline. Phosphorus concentrations frequently are high while nitrogen concentrations are relatively low. Prairie lakes exhibit a wide range of properties and are ideally suited for comparative lake studies. Our investigations of these unique ecosystems enable us to test the predictive limits of various limnological models. Ultimately, this will allow for improved ecosystem modelling and water quality guidelines for prairie lakes. Overall, our studies will lead to a better understanding of the dynamics of prairie lake ecosystems and how these ecosystems respond to eutrophication (higher concentration of nutrients), food web manipulations, and global warming. Current work includes investigation of nutrient dynamics and zooplankton community structure and population dynamics in several lake ecosystems.

Brine shrimp: sustainable fisheries

Brine shrimp (*Artemia* sp.) are abundant in many saline lakes and are harvested commercially. Brine shrimp fisheries were particularly large during the 1960s to mid 1970s when up to 140,000 kg of shrimp and 32,000 kg of their eggs were harvested annually. The fishery has not remained constant over the years, however. Problems associated with water diversions, salinity, and algal blooms adversely affected Saskatchewan's primary *Artemia* fishery at Little Manitou. Operations at other lakes have been smaller and conducted in conjunction with ongoing sulfate mining operations. Brine shrimp fisheries represent a potentially significant source of income to prairie communities but more information is required on the ecology of *Artemia*, including factors affecting yield, their vertical distribution in the water column, and the hatchability of their eggs. The first year of NHRI's *Artemia* study focused on obtaining basic limnological information on the physical-chemical regime, nutrient dynamics, algal standing stocks, algal community structure, and *Artemia* population dynamics in four saline lakes in which *Artemia* are being harvested. The basic objective of this study is to assist the industry in developing a long-term sustainable fishery.

Wetland ecosystem vulnerability study - ground water pilot study

The purpose of this ground water pilot study is to develop a conceptual and numerical model for subsurface flow, ground-water recharge and solute transport around small wetlands. Data for validation of the model are being acquired at several small wetlands at the St. Denis research site in Saskatchewan. Particular emphasis is placed on the relationship between ground water and the wetland ecosystem, with reference to the effects of past climate changes, land-use changes, and the transfers of dissolved constituents between the surface and the subsurface. The work is being carried out in collaboration with the University of Waterloo.

Evapotranspiration and open water evaporation in a prairie environment

Evaporation is an important component of the hydrologic cycle. In the Canadian prairie region, much of which is classified as semi-arid, water is in limited supply and evaporation becomes a critical factor in water resource planning and management. In understanding climate change and assessing its effects, the correct evaluation of the role evaporation will play in a modified hydrologic cycle becomes crucial in semi-arid regions, such as the prairies, and in climate-sensitive ecosystems, such as wetlands and the boreal forest. The goals of this study are to develop and evaluate methods for estimating evaporation and regional evapotranspiration in a prairie environment; to determine the effects of advection on evaporation from small water bodies and on evapotranspiration from heterogeneous areas; and to develop appropriate relationships for estimating evaporation in special case situations, such as frozen soil, forests, and irregular terrain. Work has begun at a research site near Swift Current, Saskatchewan, to obtain water balance data for use in the work to estimate evaporation from small water bodies (e.g. dugouts); and field tests are in progress to assess shore effects and the contribution of vegetation to evaporation losses from prairie sloughs.

Radar satellite wetland monitoring

The development of satellite observation procedures with new sensors will greatly assist in assessing the vulnerability of wetlands to long-term climatic changes. Monitoring changes in the spatial distribution of surface wetness allows the effects of these changes to be modelled more accurately. The aim of this study is to develop procedures for regular, high-resolution monitoring of wetland surface moisture that will enable researchers to assess and predict changes in ecosystem status. Using infrared satellite leaf-area-index observations, researchers will determine the status of surface moisture in the absence of green vegetation (i.e. during spring ,fall and drought periods) at index target sites, and during the balance of the summer, correcting for green canopy effects.

SUSTAINABLE AGRICULTURE

With funding from the Canada-Saskatchewan Agriculture Green Plan and working with Agriculture Canada, researchers from NHRI are investigating the impacts of current irrigation practices and agrochemical use on the quality and quantity of water resources in prairie environments and testing the effectiveness of alternative methods.

Remediation of irrigation flow

To be sustainable, irrigated agriculture must be efficient in water use, preserve ground-water quality from effects of leaching, and preserve the quality of surface waters receiving irrigation return flow water. To learn more about the impact of drainage water from irrigation on river water quality and to determine the effect of wetlands on the remediation of drainage water, NHRI is conducting research at two of several drainage ditches in the Outlook irrigation district in Saskatchewan. One drainage ditch exits directly into the South Saskatchewan River and is monitored at that point. The second drainage ditch passes through a natural wetland before exiting into the river. This ditch is monitored at three locations: the first at the last location of irrigation within the district, the second immediately upstream of the wetland and the third downstream of the wetland near the point that it enters the river. Using automated water samplers, daily composite water samples (subsample collected every hour) were collected from June to October 1994. Samples are now being analyzed for nutrients and pesticides and data related to fertilizer and pesticide use patterns on surface-irrigated fields. This research is being conducted in collaboration with Agriculture Canada.

Runoff of pesticides and nutrients into small water bodies from various tillage systems.

Transport of agrochemicals in surface runoff or by leaching through the soil in ground water can cause deterioration of water quality. This has serious implications for drinking, livestock and irrigation water, as well as for aquatic biota. Since much of rural Saskatchewan relies on small reservoirs as a source of potable water supplies, research is needed to determine if agricultural practices are causing an accumulation of agrochemicals in surface water and to find methods for improving agricultural management practices. This study evaluates various agricultural practices with reference to their impact on the quantity and quality of surface water supplies at research sites in the black, dark brown and brown soil zones of Saskatchewan and Manitoba. The findings of research will support management recommendations regarding sustainable agricultural practices that will reduce contamination risks to surface and ground water resources.

Irrigation management practices

Efficient sprinkler irrigation results in virtually no runoff and thus does not contribute to off-target transport of herbicides and nutrients. However, as with surface methods of irrigation, there is the potential for leaching and/or preferential flow of both nutrients and herbicides through the vadose or unsaturated zone to ground water. NHRI's fall leaching studies on a tile-drained site on the Saskatchewan Irrigation Development Centre at Outlook have demonstrated that nutrients, nitrogen and phosphorus, and several herbicides (2,4-D, MCPA, mecoprop, dicamba, bromoxynil, diclofop and clopyralid) are not only leached to depth within the vadose zone, but can also move through

the vadose zone by preferential flow. Such movement has the potential to contaminate ground water, and, as ground water is used as potable water not only by farm families but also by rural and urban communities, contamination may jeopardize community health. On-going work will contribute scientific information on which to base sustainable irrigation guidelines for use by producers and the agricultural research community. Particular areas of interest are the practice of fertigation (simultaneous application of fertiliser and water) and the use of a light sprinkle prior to sprinkler irrigation.

Leaching management

Scientific evidence is needed to demonstrate the fate of applied agrochemicals and to develop regulations that allow continued use of "safe" agrochemicals and identify those chemicals that will cause ground water contamination. This study will determine if there are risks to the environment from herbicides and fertilizers currently in use in Saskatchewan. A field calibrated model will allow the evaluation of a range of management scenarios and identify best management practices that minimize environmental threat and maximize economic benefit. The long-term goals of the research are to determine the leaching and degradation characteristics of pesticides and nutrients in the unsaturated zone: to evaluate the effects of different irrigation and land management strategies on pesticide and nutrient leaching: and to identify land management strategies that will ensure the mutual sustainability of prairie agriculture and the quality of water resources.

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